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ANTENNA RADOME FOR

MICROWAVE LANDING SYSTEM

by

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17. Abstract

A study was performed to design radomes for a Microwave Landing System (MLS). A literature search examined such topics as radome construction techniques, hydrophobic treatments, and required specifications. A specification was prepared and a design exercise carried out. A sandwich type construction was chosen. A teflon layer and heating wire grid were included to provide hydrophobicity and de-icing, respectively.

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17. Résumé

Ce rapport rend compte d'une étude préliminaire devant mener à la conception de radomes adaptés aux besoins d'un système électronique d'atterrissage (MLS). Une recherche documentaire a été faite relativement aux techniques de fabrication des radomes, aux revêtements hydrophobes et aux caractéristiques techniques à exiger. Un devis de performance a été élaboré, puis l'étude elle-même du radome a été réalisée; elle a débouché sur un radome de type stratifié ou "sandwich". Un revêtement hydrophobe en teflon et un réseau de fils électriques chauffants pour le dégivrage ont également été prévus.

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SUMMARY

This study evaluated the current state of radome design and in particular how it applied to radomes for Microwave Landing Systems (MLS). MLS will become the world's standard landing aid over the next twenty years. The system has two large aperture phased array antennas that require radomes.

The literature search concentrated on the aspects of radome design that apply to MLS. Three types of planar radomes were examined:

- half wave radome
- thin wall radome
- sandwich radome

This study included consultation with several radome manufacturers and designers. Also studied was the question of hydrophobicity because of the profound effect sheeting water has on the transmitted signal.

A design specification was drawn up and designs, using the various radomes, compared against it. The best overall choice is the sandwich radome which combines good electrical properties with the necessary rigidity. An outside layer of Teflon material will be used for hydrophobicity and a grid of embedded wires provides de-icing capability.

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1. INTRODUCTION

1.1 Project Organization

The purpose of this study is to gather relevant material and perform an engineering design of a radome for a Microwave Landing System (MLS). This material will also have relevance for design of radomes for other systems that operate near the MLS frequency of 5 GHz. The project consisted of three phases:

- gathering of information through a literature search, obtaining appropriate specifications, and some preliminary analysis.
- preparation of a design specification for the radome based on system specifications.
- an engineering design that drew on gathered material and consultation with fabricators and designers to meet the specifications in the most cost effective manner.

The structure of this report reflects these phases. Part 2 is a general discussion of the requirements for the radome. Part 3 sets down the specifications that the radome must meet. The engineering design is described in Part 4. Part 5 outlines the conclusions of this study and comments on areas where further investigation is needed.

1.2 Microwave Landing System

The Microwave Landing System (MLS) has been developed over the past decade as the replacement airport precision landing system for the current Instrument Landing System whose technology has become dated. A comparison between the two systems is provided in Figure 1.

The MLS consists of two antenna installations on the runway to be serviced. The azimuth antenna (AZ) is located on the runway centerline at the far end of the runway. Its phased array antenna produces a beam that is very narrow in azimuth and 15° in elevation. This beam is swept to and fro 40° at a precise speed allowing the receiving equipment to derive its azimuth position by timing between the arrival of to and fro scans. The elevation antenna (EL) is located at the near end of the runway off to one side. It produces a complementary beam to the AZ which is ±40° about the centerline horizontally,

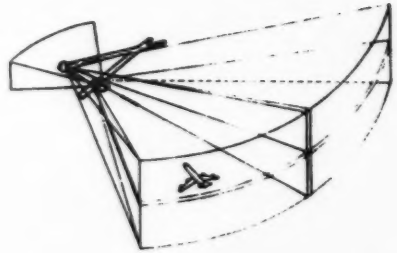
PRESENT

INSTRUMENT LANDING SYSTEM (ILS)

1. WW II DESIGN
2. LIMITED PRECISION
3. SINGLE APPROACH PATH
4. 40 FREQUENCY CHANNELS
5. LARGE FIXED GROUND INSTALLATION
6. COSTLY SITE PREPARATION
7. IMPRACTICAL OUTSIDE LARGE AIRPORTS

FUTURE

MICROWAVE LANDING SYSTEM (MLS)



1. 1980's TECHNOLOGY DESIGN
2. HIGH PRECISION FOR ZERO-ZERO LANDINGS
3. MULTIPLE APPROACH PATHS FOR JETS, STOL, HELICOPTERS
4. 200 FREQUENCY CHANNELS
5. SMALL UNITS — EASILY TRANSPORTED
6. MINIMAL SITE PREPARATION
7. CAN BE SET UP ANYWHERE, FROM LARGE AIRPORTS TO REMOTE STRIPS, HELIPADS, OIL RIGS, ETC.

Figure 1 Comparison of ILS and MLS

and very narrow vertically. It is swept from 8° to below horizontal to 15° above. The system is on a time reference period that allots certain times for the AZ and EL scans and allows the receiver to identify which is which based on a preamble at the start of each period. A typical MLS installation is shown in Figure 2.

In order to achieve the narrow beamwidth and the system accuracy, a fairly large number of transmitting elements is required. In the AZ system there are 54 slotted waveguide elements resulting in aperture approximately 1.5 metres high and 2 metres wide. The EL system is based on horns so it has a narrower aperture approximately 0.5 metres wide and 3 metres high.

1.3 Radomes

The word radome derives from the contraction of the words RAdar and DOME as these structures were originally devised to protect radar antennas from the environment. These original radomes were the familiar geodesic type domes used extensively for land based military radars but the term has come to apply to any dielectric structure used to protect an antenna from the environment. Thus, the goal of the radome is to contain the antenna in a controlled environment where its performance can be optimized while remaining as transparent as possible to the signal that is being transmitted or received. The result of this study is a radome that comes closest to meeting this transparency requirement in a way that protects the antenna and is cost effective.

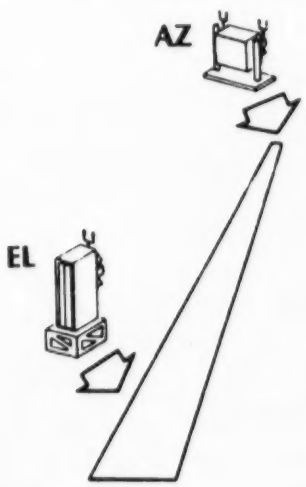


Figure 2 Typical MLS Installation

Figure 3 Radome of a Military Radar

2. RADOME DESIGN CONSIDERATIONS

2.1 Background

A radome is a device to protect an antenna from the environment while not impairing the performance of the antenna electrically. It is usually constructed of low loss dielectric material of thickness of at most one wavelength. The radome can be of complex or simple construction and of any particular shape that is required to meet the application.

Radomes can distort the fields of the antennae they protect by causing

- signal attenuation
- phase change
- depolarization
- rotation of polarization
- reflection
- refraction

These effects will result in such undesirable results as error in beamwidth, side-lobe level, signal direction, or polarization. Structurally the radome must withstand external loads such as wind and ice with permanent deformation, not absorb water which will gradually change its characteristics, and be resilient to abrasion by dust and small stones.

2.2 Radome Materials and Construction

The primary material used in Radome construction is glass fibre reinforced plastics which differ from commercially available fibreglass in that the plastic itself is chosen for its dielectric properties. Typically the dielectric constants for these types of materials are between 2 and 5. The glass fibres provide very high tensile strength, low moisture absorption, and satisfactory electrical properties.

The plastics themselves fall into two categories, either polyesters or phenolics. The latter are a solid at room temperature and must be dissolved first and then when laid up in the appropriate shape must be cured with both heat and pressure. The polyesters are cured using a catalyst and a moderate amount of heat.

Radomes are grouped into three basic types based on their construction.

- Single Layer Rigid Radome is a simple sheet of dielectric material that is thick enough to be rigid. Optimal electrical performance for this type of construction is achieved when the thickness is a half wavelength.

- Single Layer Thin Wall Radome is again a simple sheet of dielectric material but kept thin enough to approximate a zero thickness when compared to the wavelength. The radome is however quite flexible and must be kept rigid by using either air pressure evacuating or pressurizing the MLS antenna shelter, or keeping it under tension in some kind of mounting arrangement.

- Multiple Layer or Sandwich Radomes use a combination of different materials in layers to achieve a radome with whatever characteristics are required. Most common of these is the "A" type sandwich, illustrated in Figure 4, which uses two skin layers of high strength dielectric material along with a core of low-loss, light weight material such as foam or honeycomb material. The end product has close to the same physical strength as the half wave radome but weighs less and has superior transmission characteristics. The core materials typically have a dielectric constant between 1 and 1.4. These sandwich type radomes are laid up in layers. In the case of the solid honeycomb materials, these are just another layer that can be laid up on the same mould. For foam materials two moulds are used for the front and back layers and then positioned so the foam can be inserted between them.

Thin layers of material are often added to the outside of any type of radome for protection from abrasion, ultra violet light, or environmental effects. These materials are usually in such thin layers as not to affect the electrical characteristics of the radome.

2.3 Environmental Considerations

The radome's only function is to protect the antenna from the environment. In Canada, a system will face some of the most demanding environmental conditions found anywhere, particularly in the case of wind and ice loading. Ice accretion rates have been recorded in Newfoundland and Labrador in excess of 12 mm per hour at temperatures down to -10°C. This puts a considerable load on the deicing system of antenna installation. Wind loading in Canada can be up to 190 to 210km/h in some areas and an MLS at the end of a runway must withstand 240 km/h jet blasts from departing aircraft.

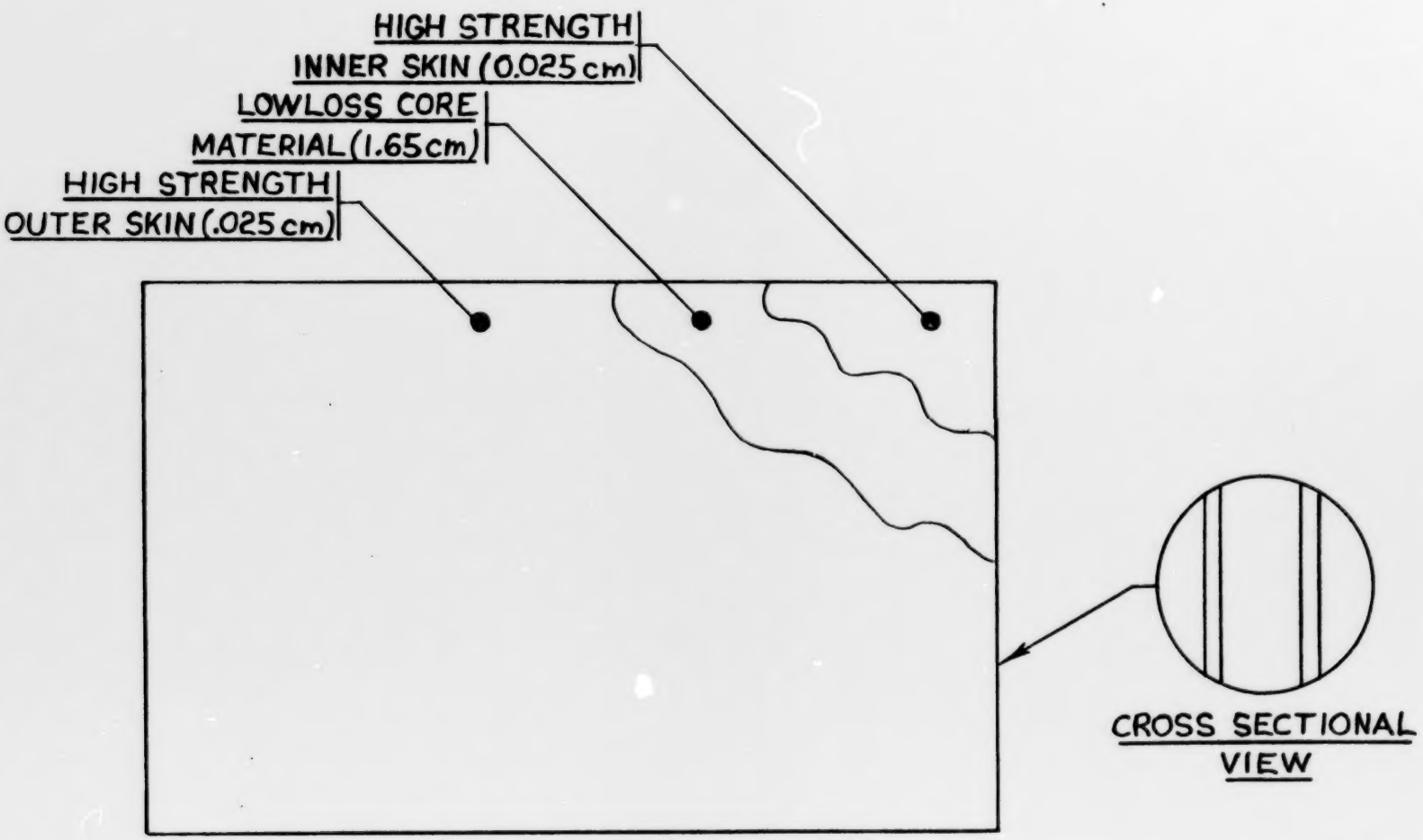


Figure 4 Sandwich Radome

	Dielectric Constant	Loss Tangent
Honeycomb		
Nylon Phenolic 3/16	1.20	0.002
Paper 3/4	1.03	0.001
Foam		
Urethane 1016/ft^3	1.16	0.0024
Polystyrene 1016/ft^3	1.16	0.0002
Laminates		
Selection 5003	4.2	0.012
Cordo H200C	4.3	0.010
U.S. Poly P680	4.3	0.012
Tonox	4.4	0.016
Teflon	2.08	0.0004
Duroid	2.7	0.003
Water	6.3	0.55
Snow	1.3	0.0005
Ice	3.2	0.0008

Table 1 Dielectric Properties of Selected Materials

Rain is also a problem with MLS radomes as sheeting action that produces a film of 0.05 cm on the radome can attenuate signals up to 6dB. As a result, a significant amount of work has gone into investigating coatings that exhibit hydrophobic (water shedding) characteristics. Compounds such as Teflon, Fumed Silicon Dioxide (FSD), silicone, vegetable base lubricants, Mylar, etc, have been tested with no one substance emerging as a clear winner. FSD compounds perform best in the short term but tend to loose their effectiveness in four to six months. Teflon is not as good as FSD in shedding water but its performance holds up better over the years. More work is going on in this field with FSD, modified for longer life, probably becoming the eventual winner.

2.4 Structural Strength of Radomes

The radome must maintain the structural integrity of the antenna enclosure under the environmental conditions to be encountered in the field. Principal among these is wind loading as a 160 kilometre per hour wind will produce 2011 Newtons per square metre of pressure on the radome. Short duration jet blasts will cause up to 5000 Newtons per square metre for short periods of time. Since the radome is mounted in a vertical plane accumulation of precipitation on the surface is not a structural problem.

3. RADOME DESIGN SPECIFICATION

3.1 Microwave Landing System Requirements

The general specifications, as laid down by the United States Federal Aviation Administration, FAA, as they reflect on the radome design are as follows:

1. Antenna radomes will have de-icers which will be automatically activated only during periods of ice accumulation and capable of keeping the radome free of ice down to a temperature of -7 degrees celsius with winds of at least 60 KPH from any direction.

2. Antenna radomes will be designed such as to prevent rain from standing on or flowing in sheets across the surface of the Radome. If a non wetting coating agent is used, it shall have an operational life of at least one year.

3. The antenna shelter must be sealed against the weather in such a matter as to permit removal and replacement of the radome without the necessity of using sealing compounds.

In addition to these specific requirements the radome must also conform to the environmental requirements.

- up to ten centimetres of rain per hour
- snow loading of 2000 Newtons per square metre
- wind up to 160 km per hour from any direction
- jet blasts of 240 km per hour for up to a minute

3.2 Construction

The radomes must be of suitable size to cover the aperture. In the case of the AZ system the radome must be 132 cm high and 214 cm wide. For the EL system the aperture has not been completely designed but the dimensions will be approximately 25 cm wide and 380 cm high.

The construction of the radome must be such that it provides rigid surface either of its own make up or through some method of support.

The radome must be mounted in such a way as to be easily removeable from the front of the antenna shelter for replacement. It must be weather proofed without the use of sealing compounds.

3.3 Electrical Requirements

The radome must not attenuate any transmitted signal anymore than 0.2dB for any incidence angle. The change in insert phase over the range of incidence angles shall be less than 5^{o}.

3.4 Environmental Requirements

The radome must meet the environmental conditions set down for the whole system in sub-section 3.1. In addition, the radome surface may not permit water from standing or flowing in sheets across the surface. The system must also be able to shed ice down to -15^{o}c with winds of 90 KPH from any direction.

The radome must further maintain its operational characteristics to -40^{o}C which is the required operating temperature under non-icing conditions.

The radome must withstand long term exposure to ultra-violet light and maintain proper operating characteristics.

4. RADOME DESIGN

4.1 Background

In the final analysis there are several choices to be made in designing the radome

- type of radome construction
- method of de-icing
- surface preparation for watershedding

Beyond these three choices the engineering analysis deals only with details. This detailed analysis, however, is the basis for making the choices so each will be examined in turn and evaluated against the others.

4.2 Construction

The most straight forward approach to meeting the requirement of easy replacement of the radome is to mount the radome to a metal frame and bolt this frame onto the front of the antenna enclosure using a gasket. The thin wall and sandwich radomes would definitely need a frame but the half wave may be able to be formed to mount directly without the frame.

As far as the radome is concerned the only difference between the elevation (EL) and azimuth (AZ) antenna subsystems is different dimensions so no special analysis of one versus the other is deemed necessary.

The major considerations as far as the electrical properties of the radome are concerned are:

- what proportion of the transmitted energy is reflected by the radome.
- what portion of energy is absorbed by the radome.
- what errors will be caused by the radome bending the direction of the transmission.

From a mechanical point of view the radome must have sufficient strength to withstand the pressure applied to it by the wind. All three radome designs below easily meet this mechanical requirement.

4.2.1 Half Wave Radome

The optimum thickness for a solid radome to avoid reflections is a multiple of the half wavelength. Customarily the first multiple is chosen to avoid losses related to the thickness of the material. The zero multiple is a special case where the material is kept very thin compared to the wavelength and will be discussed separately below. For a half-wave radome the optimum thickness, d, for normal incidence is

$$d = \frac{\lambda}{2((e/e_o)-1)^{\frac{1}{2}}}$$

λ = free space wavelength
e = dielectric of the radome
e_o = free space dielectric

For an MLS with a mean frequency of 5045 MHz the optimal thickness for a radome with a relative dielectric of 4 is 1.488 cm. This material is standard laminate material for radomes that provides rigidity while maintaining reasonable electrical properties. This material has a loss tangent of 0.010 which results in an absorption loss of 0.13 dB for normal incidence and 0.19 dB for the maximum scan angle of 40°. No power is lost through reflection at normal incidence but 0.12 dB is lost through reflection at 40°. The insert phase of the radome is 89.97° at 0° incidence and 93.58° at 40°.

4.2.2 Thin Wall Radome

A thin wall is an approximation to the zero multiple of the half wavelength. In the case of a thin wall of a laminate with a relative dielectric of 4, a loss tangent 0.010 and a thickness of 0.0635 cm. the loss due to reflection is 0.004 dB at normal incidence. At the maximum scan angle of 40° loss due to reflection is 0.069 dB. At normal incidence the loss due to absorption is 0.003 dB while at 40° the loss due to absorption is 0.004 dB. The insertion phase for normal incidence and 40° incidence are 5.73° and 10.11° respectively.

The thin wall radome is not rigid on its own and must be held rigid either by applying tension with its frame or by pressurizing or evacuating the antenna shelter to ±4 psi.

4.2.3 Sandwich Radome

The sandwich radome consists of three layers consisting of thin laminate skins on the outside and a low loss core of honeycomb material. Given outside skin

thickness of 0.025 cm the optimum core thickness for zero reflection at normal incidence, the core material should be 1.65 cm thick. This results in a loss from reflection of 0.082 dB at the maximum scan angle of 40°. Loss due to absorption is 0.018 dB at normal incidence and 0.023 dB at the maximum scan angle. The insertion angles are 12.07° for normal and 40° incidence.

4.2.4 Design Trade-Off

The half wave radome exceeds the design requirement for signal transmission. Otherwise it has the advantages of being rigid and of simple construction. Its insertion angle characteristic is very similar to the others.

The thin wall exhibits the best electrical properties and the simpliest radome construction. Consideration of this approach is complicated by the requirement to keep the radome rigid either by tension, which can lead to eventual stretching deformation, or by a system to pressurize or evacuate the antenna enclosure.

The sandwich design provides close to the same electrical properties as the thin while having the inherent rigidity of the half wave wall. It has a layered construction that lends itself to the implantation of heating wires. Although the thin wall has good electrical properties the added system cost of pressurizing the antenna shelter or the shortened life span due to stretching deformation under tension make it an undesirable choice. The higher construction costs of the sandwich radome are offset by its expected long, trouble free lifespan.

4.3 De-Icing

There are two basic approaches to the de-icing problem with radomes and both have been used successfully. To a large extent the choice between embedded heating wires and a hot air blower depends on the type of radome construction. Embedded wires are most efficient in the sandwich type radomes as the wires can be placed between the core and the outside layer and the heat does not have to penetrate the core which acts as an insulating layer. The hot air blower is better suited to the thin wall type radome where there is a minimum of dielectric to penetrate.

Either system is capable of delivering the 0.23 watts/sq. cm. required to keep the radome clear under expected icing conditions. The wire grid provides the heat more efficiently but will cause the radome fabrication to be more expensive. All indications are, however, that this will be less expensive than a blower system which will probably have to be insulated from the electronics to avoid

overheating. The heating of the radome will also be more uniform with the wires than a blower system which are notorious for hot and cold spots on the radome surface.

The wire grid, placed horizontally so as to be perpendicular to the E field, will also attenuate horizontally polarized components of the transmission.

A wire grid using 15Ω/cm. nichrome wire with .76 cm. spacing between the wires will provide the necessary heat. The wires will be bonded to a power bus on either side of the radome and will be fed with mains AC power. Total power dissipation while de-icing will be 6000 watts for the AZ radome and 2300 watts for the EL radome.

4.4 Hydrophobicity

The remaining characteristics are concerned with the ability of the surface to shed water. There has been considerable study of this subject over the last several years that have shown that although FSD surface treatments have shown the best hydrophobicity in the short term, the surface deteriorates within six months. This falls well short of the FAA requirement for annual reapplication and until this requirement can be met these surface treatments are unacceptable. Other materials such as HM0D4 and vegetable lubricants also deteriorate quickly and must be reapplied to maintain performance.

Teflon surfaced radomes also showed some deterioration initially but after a simple cleaning returned to their initial characteristics. Cleaning did not help radomes with surface treatments. Teflon had a hydrophobicity slightly inferior to FSD but its ease of maintenance clearly makes it the only choice to meet the specifications.

4.5 Specification for the Azimuth Radome

In order to have an operational area of 132 cm by 214 cm the frame supporting the radome will be 150 cm x 240 cm. This will allow sufficient space for the interface between the radome material and the metal frame, a mounting flange, and the buses for the de-icing wire grid. The mounting flange will be suitable to be mounted onto the antenna shelter using a gasket to weatherproof the interface. The radome material must also be attached to the frame in a weatherproof fashion.

The radome itself must be constructed in layers as follows:

- 0.004 cm Teflon fabric
- 0.025 cm Microwave quality Laminate (e = 4.0 @ 5 GHz)
- 0.003 cm De-icing wire grid
- 1.65 cm Paper/Resin Honeycomb (e = 1.04 @ 5 GHz)
- 0.025 cm Microwave quality Laminate (e = 4.0 @ 5 GHz)

Surface finish of the outside surface 0.0001 cm RMS. Tolerance in all thicknesses must be 10% of thickness or 0.05 cm whichever is less. Overall thickness of radome to be within ±0.05 cm.

Wire grid to be electrically bonded to 0.01 cm thick copper bus strips along vertical edges of radome. Suitable external connections to be provided at bottom end.

Elevation radome will be of similar construction but is not well enough defined at this time to specify.

5. CONCLUSIONS

The radome best suited for the microwave landing system application is a sandwich radome that will include a grid of heating wires for de-icing and a thin layer of teflon on the surface for hydrophobicity. From discussions with several potential manufacturers, this type of radome will cost approximately $1500 - $2000 in modest production quantities. Their experience indicates that theoretical design numbers can be met by this type of radome.

Further consideration must be given to hydrophobic coatings as work on these products should soon produce an FSD coating that will out perform Teflon and last the required year in the field.

CONSULTANTS AND POTENTIAL SUPPLIERS

1. Meyer Associates Inc., Framingham, Mass., U.S.A.
2. Canadian Astronautics Limited, Ottawa, Ontario
3. Protective Plastics Limited, Scarborough, Ontario
4. Electronic Space Systems Corporation, Concord, Mass., U.S.A.
5. Chu Associates Inc., Littleton, Mass., U.S.A.

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